AD A283772

RAND

A Two-Phased Approach to Model Validation for the Susceptibility Model Assessment and Range Test (SMART) Project

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Prepared for the United States Air Force

Project AIR FORCE

[illegible] ...arch reported here was sponsored by the United States Air Force [illegible] ...tract F49620-91-C-0003. Further information may be obtained [illegible] ...rategic Planning Division, Directorate of Plans, Hq USAF.

Library of Congress Cataloging in Publication Data

Born, Gregory, 1951–
A two-phased approach to model validation for the susceptibility model assessment and range test (SMART) Project / Gregory Born.
p. cm.
"Prepared for the United States Air Force."
"MR-399-AF."
Includes bibliographical references.
ISBN 0-8330-1554-0
1. United States. Air Force—Weapons systems. 2. Weapons systems—Mathematical models—Evaluation. I. United States. Air Force. II. RAND. III. Title.
UG633.B683 1994
358.4'082—dc20 94-19233
CIP

Published 1994 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
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PREFACE

This report proposes a preliminary framework for model validation to be used in the overall model assessment methodology being developed under the auspices of the Susceptibility Model Assessment and Range Test (SMART) Project. This model validation framework is based on an analogy between model validation and weapon system test and evaluation and builds on important validation efforts already completed and demonstrated in the SMART Proof-of-Concept. The focus of this initial effort is on the validation of sensor and weapon system models; however, the methodology is potentially extendable to broader model classes.

This work, being conducted under the SMART Model Validation Study, was initiated in April 1993 with funding provided to the RAND Project AIR FORCE (PAF) contract via Military Interagency Purchase Requisition (MIPR) from the SMART Project Office. The study is being conducted under the Force Employment Project within PAF, which is sponsored by the Air Force Director of Plans (AF/XOX). The Air Force point of contact for the study is Mr. Allen Murashige of the Air Force Studies and Analyses Agency (AFSAA).

This document is provided to the SMART Project Office in accordance with task one of the RAND statement of work and should be of general interest to anyone concerned with the credibility of military modeling and simulation.

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Project AIR FORCE is operated under Contract F49620-91-C-0003 between the Air Force and RAND.

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SUMMARY

The Susceptibility Model Assessment and Range Test (SMART) Project is a joint-service initiative tasked to define a model credibility assessment methodology that will assist DoD decisionmakers with model accreditation decisions. This methodology will integrate the key features of verification, validation, and configuration management and, as the project name implies, will base most of the validation efforts on comparisons with range test data. The various elements of the SMART methodology will be demonstrated by an actual application to a set of five susceptibility models selected by a joint-service prioritization.

This report describes a two-phased approach for the SMART model validation component of the overall methodology and is based on an analogy between model validation and weapon system test and evaluation. It incorporates the functional element decomposition and validation previously developed for the SMART project as Phase I and adds an integrated model validation as Phase II. Neither Phase I nor Phase II alone is sufficient for model validation, but together they provide a complementary and powerful methodology. The functional element validation focuses on intermediate quantities usually inaccessible at the integrated model level and avoids the aggregation and compensation of errors often found in integrated model outputs. On the other hand, even when all functional elements are valid, the integrated model results may still be invalid since some critical functional elements may be missing in the model or may be incorrectly integrated. The Phase II validation is designed to reduce this possibility.

As described in Section 2, the objectives and procedures for Phase I and Phase II validation are fundamentally different. The objective of the functional element validation is to determine how accurately each functional element of the model performs as compared to the actual system component it is intended to represent. In this case, usually the model must be decomposed into modules representing individual functional elements, and separate software drivers must be developed to execute these modules and output the performance characteristics of interest.

Owing to the detailed, technical characteristics of the functional elements typically found in sensor and weapon system models, scientific and technical intelligence (S&TI) data are more appropriate tnan flight test data for their validation. The functional element decomposition also requires a software familiarity that usually only the software developers possess; consequently, they are integral to this phase of the validation.

The objective of the integrated model validation is to determine how accurately the model as a whole predicts operational capabilities of an actual sensor or weapon system. The four-step procedure described consists of identifying critical analytical issues (CAIs), defining measures of effectiveness (MOEs), designing and conducting specific tests to resolve CAIs, and analyzing and documenting the results. Owing to the operational nature of the Phase II validation, operational flight test data should be used for model comparisons. To avoid any appearances of prejudice, the Phase II validation should be conducted by someone other than the model developers. Ideally, the Phase II validator will have appropriate analytical and operational expertise in addition to model familiarity.

Section 3 describes generic Phase II model validation objectives for the general class of aircraft susceptibility models. CAIs can be categorized by the different phases of a weapon engagement. Four phases are identified and consist of: target detection, target tracking, weapon flyout, and weapon intercept. Some susceptibility models such as sensor models may model only the target detection or detection and tracking phases while missile and gun models will model all four phases. Operational MOEs for each phase are also proposed in this section.

Section 4 illustrates how the generic Phase II model validation template is used to develop model-specific CAIs for two models: the Enhanced Surface-to-Air Missile Simulation (ESAMS) and the Advanced Low-Altitude Radar Model (ALARM). Tentative lists of CAIs and appropriate MOEs are presented. General test procedures and data analysis for each CAI are more fully described in the notional test plans presented in Appendices A and B.

Section 5 acknowledges the practical difficulties of completing a comprehensive model validation based exclusively on comparisons to test data but argues that comprehensive model validation is not necessary for the majority of model applications. By decomposing the validation requirements into multiple, independent CAIs, only the CAIs relevant to the application of interest must be validated. Based on the most common model applications, some CAIs are more important than others, and Section 5 proposes a prioritization scheme for initial validation of ESAMS and ALARM.

ACKNOWLEDGMENTS

Funding for this work was provided to the RAND Project AIR FORCE contract via MIPR from the SMART Project Office. The author would also like to thank James Dewar who reviewed the draft manuscript and offered several suggestions for improvement.

ACRONYMS

AAA	Anti-Aircraft Artillery
AAM	Air-to-Air Missile
AASPEM	Air-to-Air System Performance Evaluation Model
AFSAA	A.r Force Studies and Analyses Agency
AF/WL	Air Force/Wright Laboratories
AGC	Automatic Gain Control
AGL	Above Ground-Level
ALARM	Advanced Low-''titude Radar Model
CAI	Critical Analytical Issue
COEA	Cost and Operational Effectiveness Analyses
COI	Critical Operational Issue
CPA	Closest Point of Approach
CW	Continuous Wave
DECM	Deceptive Electronic Countermeasures
DMA	Defense Mapping Agency
DMSO	Defense Modeling and Simulation Office
DT	Developmental Testing
DT&E	Developmental Test and Evaluation
ECCM	Electronic Counter-Countermeasures
ECM	Electronic Countermeasures
ESAMS	Enhanced Surface-to-Air Missile Simulation
ESL	Encounter Simulation Laboratory
FAT	Functional Area Template
FME	Foreign Materiel Exploitation
GAO	General Accounting Office
IR	Infrared
JTCG/AS	Joint Technical Coordinating Group/Aircraft Survivability
LFT	Live Fire Test
LIMSCOPE	Limitation to Scope (of testing)
LO	Low Observable
MIPR	Military Interagency Purchase Requisition
MITL	Man-in-the-Loop

MOE	Measure of Effectiveness
MOP	Measure of Performance
MORS	Military Operations Research Society
MSL	Mean Sea-Level
MTI	Moving Target Indication
OSD	Office of the Secretary of Defense
OT	Operational Testing
PK	Probability of Kill
PRF	Pulse Repetition Frequency
RADGUNS	Radar-Directed Gun Simulator
RCS	Radar Cross Section
RF	Radio Frequency
RMS	Root Mean Square
SAIC	Science Applications International Corporation
SAM	Surface-to-Air Missile
SEKE	Spherical Earth Knife-Edge
SIMVAL	Simulation Validation
SMART	Susceptibility Model Assessment and Range Test
SNR	Signal-to-Noise Ratio
S&TI	Scientific and Technical Intelligence
TBJ	Terrain Bounce Jamming
TECHEVAL	Technical Evaluation
TEMP	Test and Evaluation Master Plan
TRAP	Trajectory Analyses Program
TSPI	Time-Space-Position Information
VHF	Very High Frequency
VV&A	Verification, Validation, and Accreditation
XOX	Director of Plans

1. INTRODUCTION

As modeling and simulation continue to pervade every area of the Department of Defense (DoD) and become standard tools for decision-making, the consumers of modeling and simulation results have become more critical and now require evidence that the modeling and simulation results accurately reflect real-world outcomes. This concern is reflected, for example, in several General Accounting Office (GAO) reports [1,2] and DoD Directive 5000.2 [3] that require verification, validation, and accreditation (VV&A) for all modeling and simulation used in any phase of weapon system acquisition. While some VV&A has been attempted in the past, these efforts have not been widespread, consistent, or adequately documented.

The difficulty of precisely defining VV&A, let alone establishing standard VV&A procedures, is contributing to the VV&A problem. This is a consequence of the many diverse applications of modeling and simulation. For military modeling and simulation, the DoD is developing formal definitions of VV&A and will issue them shortly in the form of a DoD Directive. Recently, the Military Operations Research Society (MORS) published a collection of papers on the subject stemming from its Simulation Validation (SIMVAL) series of workshops [4]. It includes a reprinted version of a RAND study done specifically for the Defense Modeling and Simulation Office (DMSO), which reflects the conclusions of a DMSO VV&A working group and discusses both subtleties of VV&A and procedural approaches [5]. References 4 and 5 are consistent in their essential features and definitions. Also see Reference 6 for a discussion of limitations in our ability to validate models. It proposes a number of alternative criteria for model evaluation.

Of the primary components of model credibility assessment, namely, verification, validation, and configuration management, validation is the component concerned with comparisons of modeling and simulation results to real-world outcomes. MORS defines validation as "the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model"

[4]. Potentially, there are many approaches to model validation ranging from comparisons with the judgments of domain experts (i.e. "face" validation), comparisons with intelligence data or other validated model results, comparisons to validated hardware simulators, and comparisons with test data from laboratory and field testing of the real system.

The Susceptibility Model Assessment and Range Test (SMART) project is a joint-service initiative established in FY91 under the Joint Technical Coordinating Group/Aircraft Survivability (JTCG/AS) and funded by the Developmental Test and Evaluation office Live Fire Test office within the Office of the Secretary of Defense (OSD/DT&E/LFT) with the purpose of developing a joint-service model credibility assessment methodology. The SMART project is focused on the VV&A of a limited set of aircraft susceptibility models[1] and as the name implies, advocates an approach to model validation that emphasizes the comparison of modeling and simulation results to operational flight test results.

Recognizing that many aircraft susceptibility models have similar modeling components or functional elements, the original SMART approach started with the decomposition of a given susceptibility model into common functional areas. Each functional area is further decomposed into functional elements as illustrated for radio-frequency (RF) sensors in Figure 1.1 [7]; then the same functional element in all models can be validated with a common database of test results. This approach potentially avoids the redundant and costly testing otherwise necessary to validate each model.

Currently, the functional element decomposition has been applied to three models: ESAMS, ALARM, and the RADGUNS model [7,8]. Five functional elements in ESAMS and ALARM were compared with both scientific and technical intelligence (S&TI) data and flight test data from the ICON GLASS exploitation effort during the SMART Proof-of-Concept [9,10]. These comparisons served two purposes: (1) to refine

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[1]The SMART model set includes five models: Enhanced Surface-to-Air Missile Simulation (ESAMS), Advanced Low-Altitude Radar Model (ALARM), Radar-Directed Gun Simulation (RADGUNS), the Trajectory Analyses Program (TRAP), and the Air-to-Air System Performance Evaluation Model (AASPEM).

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- Target Characteristics
  - Flight Path
  - Signature
    - RCS
      - Static
      - Dynamic
    - Fluctuations
  - Electronic Countermeasures (ECM)
    - Noise
      - On Board
      - Off Board
      - Standoff
    - Deceptive
      - On Board
      - Off Board
- Propagation
  - Masking
  - Clutter
  - Multipath/Diffraction
  - Atmospheric Attenuation
- Transmitter
  - Waveform Generator
- Receiver
  - Thermal Noise
  - Automatic Gain Control (AGC)
  - Detector
  - Blanking
- Antenna
  - Gain
- Signal Processing
  - Threshold
  - Clutter Rejection
    - Moving Target Indication (MTI)
    - Doppler Filters
  - Integration
  - Pulse Compression
- Target Tracking
  - Angle
  - Range
  - Doppler
  - Antenna Scan

Figure 1.1—Radio Frequency Functional Area Template

various generic model components by using threat-specific data from the S&TI and (2) to identify modeling errors.

Several errors were successfully identified in both ESAMS and ALARM during the proof-of-concept [10,11] and convincingly demonstrate the value of the functional element decomposition and validation. Of particular significance, two problems discovered in ALARM compensated one another at the integrated model level. One was a moving target indication (MTI) modeling error that resulted in an overestimation of signal-to-noise ratios (SNR); the other was the neglect of tracking errors that underestimated the SNR [11]. Compensating errors of this type are extremely difficult to identify in an integrated-model approach to validation and demonstrate that functional element validation is a necessary first step.

On the other hand, the validation of the individual functional elements alone is not sufficient evidence that the overall model is validated. The basis for this assertion is that all models are only approximations of the real world, and any neglected aspect whether intentional or unintentional could potentially invalidate the overall model even when all modeled functional elements are valid. Also, validated functional elements could be improperly integrated and result in an invalid model. Therefore, the final model output needs some validity check.

A two-phased approach to model validation that addresses both concerns combines the existing functional element validation with an integrated-model validation. This approach can be based on an analogy with weapon system test and evaluation and is described in Section 2 with an emphasis on the Phase II or integrated-model validation. Section 3 discusses generic, model-independent Phase II validation objectives for the general class of aircraft susceptibility models. Section 4 focuses on specific Phase II validation objectives for ESAMS and ALARM. Notional test plans that describe data requirements, test procedures, and data analysis necessary to resolve the specific validation issues for ESAMS and ALARM are presented in Appendices A and B, respectively. Given the limited resources available for model validation, Section 5 offers some guidance in the prioritization of

critical analytical issues (CAIs) for ESAMS and ALARM. While a comprehensive model validation may be unattainable, useful validation for the majority of common model uses is not.

2. MODEL VALIDATION FRAMEWORK

As described in the Introduction, the original SMART approach to model validation involved model decomposition into functional elements and the validation of individual functional elements. While this first step is necessary, it is not sufficient; an additional step is necessary that examines the integrated model results. In this section, we describe a two-phased approach to model validation that preserves the functional element validation as Phase I and adds the integrated model validation as Phase II. The objectives and approaches of each phase are fundamentally different and can be likened to the two phases of weapon system test and evaluation.

WEAPON SYSTEM TEST AND EVALUATION ANALOG

Before describing the two-phased approach to model validation, it is useful to briefly examine the test and evaluation of weapon systems within DoD (for further details see Reference [3]). During the acquisition process, weapon systems must pass two phases of test and evaluation before full scale production is authorized. The first phase is developmental test and evaluation; the second phase is operational test and evaluation. Without going into excessive detail, the primary objective of developmental testing (DT) is to demonstrate that a weapon system meets all technical performance requirements as specified in the Test and Evaluation Master Plan (TEMP). For aircraft weapon systems this demonstration usually consists of bench or anechoic chamber testing and limited flight testing in which the test article is instrumented to record technical performance data. This testing is conducted by technical experts and is the responsibility of the developing agency (program manager). In addition, DT is often conducted with contractor support since hardware or software modifications may be necessary to meet the system specifications.

Once a weapon system has passed the technical evaluation (TECHEVAL), it is certified ready for operational testing (OT). OT is then conducted to demonstrate that the weapon system can meet critical

operational effectiveness and suitability requirements, which collectively are referred to as critical operational issues (COIs).

Sufficient resources (e.g., number of missiles to test, funding for flight hours on a test range, or number and types of threat systems) are rarely available to complete a comprehensive operational test. Simply too many weapon system employment conditions exist to test them all with statistical confidence. The COIs help provide a focus on the most critical test conditions; however, many examples exist of weapon systems that were successfully tested and fielded yet possessed serious operational deficiencies. In spite of these limitations, OT provides an essential, independent evaluation of operational capabilities by service-representative personnel.

For modeling and simulation software, a test and evaluation or validation procedure can be established by analogy. The "DT phase" may be defined to consist of the functional element decomposition and the comparison of functional element performance to test data, while the "OT phase" may be defined to consist of an evaluation of integrated model performance.

PHASE I: FUNCTIONAL ELEMENT VALIDATION

The objective of the functional element validation is to demonstrate that the individual functional elements of the model accurately represent the performance or characteristics of the corresponding target or weapon system attributes. First and foremost, the corresponding software modules in the model must be able to be isolated and tested independently from the rest of the model. Since this typically will not represent an intended use of the model, this testing requires software engineering to isolate a particular software module and to develop the necessary off-line drivers to test them. This software engineering requires a code familiarity that usually only the software developers possess; consequently, they are integral to the functional element validation.

The next step is to compare the functional element performance or characteristics with actual system data. For example, the validity of a target tracking element depends on dynamic filter responses. Its

validation requires a comparison between the modeled filter response to the actual system filter response. Typically these data are available from S&TI analyses of foreign materiel exploitation (FME) where filter responses to standard step and ramp input signals are tested and documented. Given the narrow focus and generally technical nature of the functional element performance or characteristics, S&TI data and not flight test data are the appropriate source for functional element validation.

Appropriate measures of effectiveness (MOEs) or measures of performance (MOPs) to compare in the functional element validation are technical system performance parameters. These may include voltages, powers, or signal-to-noise or signal-to-interference ratios. It is the model developers again who will be the most knowledgeable in designing specific comparison tests and in choosing the appropriate measures.

PHASE II: INTEGRATED MODEL VALIDATION

The objective of the Phase II validation is to execute the model as originally intended by the model design and to compare the available outputs to performance capabilities of the real system. To achieve this objective, a number of steps will be required that can be patterned after related steps in the operational testing of weapon systems.

The first step in this process is simply to identify a list of model uses that need validation of model outputs. As in the case of operational testing, it will rarely be possible to validate the model for all possible applications. The most critical applications—namely, those for which the model will be used most frequently or those for which the model may be particularly sensitive—will be identified as CAIs in analogy to the COIs of weapon system test and evaluation. For aircraft susceptibility models, these CAIs represent issues such as the detectability of aircraft with conventional signatures (a frequent model usage), as well as the detectability of low-observable (LO) aircraft (a stressing model usage requiring accurate clutter and multipath modeling).

Weapon system COIs are usually stated as questions to be resolved in OT (e.g., "Does the system accurately detect and identify. . . ?" or

"Is the system reliable, maintainable, and available?"). Effectiveness and suitability criteria are usually provided in the TEMP, and the resolution of COIs is based on a comparison of test results to these criteria. In model validation, the situation is less straightforward. Potentially a model may be used for several diverse applications that require different degrees of accuracy. For this reason, a specific CAI would be worded to ask, for example, "How accurately does the model predict . . ." rather than "Does the model accurately predict. . . ." The determination that a demonstrated accuracy is acceptable for a specific application is a model accreditation decision and should be separate from model validation.

The next step is to identify appropriate MOEs or MOPs for each CAI. These quantities have operational and analytical significance. Example MOEs may include radar detection range, track error, missile miss distance, etc., not voltages, powers, or signal-to-interference ratios as used in the Phase I validation. These MOEs provide the basis for comparing Phase II model validation results to operational test data and consequently determine the data that are needed.

The third step is to design and conduct the tests. Similar to operational test and evaluation, a single test does not have to be designed to resolve all the critical analytical issues. Rather an incremental approach that prioritizes CAIs for resolution may be useful. This approach may allow the validation of certain CAIs and subsequent model accreditation for certain limited applications, while deferring those CAIs for which test data are unavailable or difficult to obtain such as LO detection data or fuzing and warhead data.

Another important consideration in the design of a validation test plan is the number of replications needed for each test condition to ensure that any comparisons between flight test data and model results have statistical confidence. It is often difficult to determine this number *a priori* since it will depend on the variance of the replications and the type of statistical test used and may be constrained by other factors such as available funding or range access.

The last step is to analyze and document the results. This step involves the evaluation of MOEs, comparisons between test data and model

results, and the resolution of CAIs. Unlike the situation in operational testing of weapon systems where a minimum performance threshold is usually provided to the test agency and must be met or exceeded to satisfactorily resolve a COI, generally model validation will not have threshold values. The resolution of CAIs requires a statement of model accuracy with respect to validation data and some estimate of the statistical confidence.

Just as the operational test and evaluation of weapon systems requires an independent test agency to preclude the appearance of prejudice in the testing, the Phase II validation should be conducted by someone other than the model developers. Ideally, the Phase II validator will have the appropriate analytical and operational expertise in addition to model familiarity.

3. GENERIC PHASE II MODEL VALIDATION OBJECTIVES

Aircraft survivability is defined as consisting of two major components: susceptibility and vulnerability. Susceptibility is defined as "the degree to which a device, equipment, or weapon system is open to effective attack due to one or more inherent weaknesses [3]," while vulnerability is defined as "characteristics of a system that cause it to suffer definite degradation as a result of having been subjected to a certain level of effect in an unnatural hostile environment [3]." Aircraft susceptibility models, therefore, in general are designed to predict the conditions under which aircraft can be detected and effectively attacked with sensors and weapon systems of all types. These include RF, infrared (IR), and electro-optical sensors, anti-aircraft artillery (AAA), surface-to-air missile (SAM) systems, and air-to-air missile (AAM) systems, for example.

Just as functional commonalities among different aircraft susceptibility models allow the identification of functional areas and functional elements in the Phase I validation, other model commonalities allow the identification of common validation categories in the Phase II validation. For example, the successful engagement of an aircraft can be decomposed into (at least) four engagement phases. These phases usually consist of target detection, followed by target tracking, weapon launch and flyout, and finally, weapon intercept. Each engagement phase usually has different effectiveness measures that can be examined as a function of scenario conditions such as target flight path, signature, countermeasures, and different natural environments (i.e., terrestrial and atmospheric characteristics).

Using this categorization, a generic, Phase II model validation template is presented in Table 3.1 along with important operational MOEs. The first category is target detection. This category of validation issues is common to both sensor and weapon system models, whereas the remaining categories generally apply only to weapon system models.[1]

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[1]Target tracking is a sensor function; however, tracking is only necessary to guide a weapon.

Table 3.1

Generic Phase II Model Validation Template and MOEs

Engagement Phase	Validation Issues	MOEs
Target Detection	Target Signature Target Profile Natural Environment Countermeasures	Probability of Detection
Target Tracking	Target Signature Target Profile Natural Environment Countermeasures	Track Error
Weapon Flyout	Guidance Mode Target Profile	Weapon Trajectory Velocity Profile
Weapon Intercept	Target Signature Target Size and Shape	Miss Distance Probability of Fuzing Probability of Hit Probability of Kill

The probability of detection is the primary measure of operational effectiveness in this category. The analyst is usually interested in the variability of this measure with respect to target signature, e.g., conventional versus LO, target profile (generally high versus low altitude and possibly fast versus slow when Doppler processing is involved), environmental conditions such as terrain masking, clutter, atmospheric attenuation, diffraction and multipath, and finally, target countermeasures.

The second category of generic validation issues is target tracking. The same four conditions listed for target detection are also listed for target tracking, although with subtle differences in emphasis. For example, under target signature, the magnitude of the signature is not generally an issue—since target detection is a prerequisite to target tracking—rather the shape of the signature becomes significant. For example, initial lockon may occur at a target aspect angle of high signature and subsequently lost at aspects of lower signature. Similarly, under the subcategory of target profile, the model user or analyst generally is interested in the capability of the weapon system to track maneuvering versus nonmaneuvering targets,

whereas random target maneuvers have less affect on target detection. In general, more varied countermeasures exist for degrading tracking effectiveness.

Track error is the primary MOE for target tracking. Predicted track errors plotted as a function of time or target position for nonmaneuvering targets may provide a useful validation of modeled servo responses in azimuth, elevation, range, and Doppler. For maneuvering targets or targets in the presence of countermeasures, comparing time-averaged track error distributions may be sufficient.

The third category listed in Table 3.1 is weapon flyout. Guidance mode and target profile are two conditions identified in this category. The guidance mode may be "unguided" as in the case of an anti-aircraft artillery round, or it may be one of potentially several operator-selectable modes for complex radar-guided missiles. Target profile is an important validation issue since some weapons are relatively slow and nonmaneuverable and may be defeated with simple target maneuvers, even though the target is being accurately tracked. For both conditions the primary MOEs of interest are the weapon trajectory and velocity profile.

The last category listed in Table 3.1 is weapon intercept. Two validation issues in this category are target signature and target size. Target signature is listed because weapons that use a proximity fuze to detonate a warhead require the detection of reflected target energy. The target signature seen by a weapon fuze at close range may be significantly different from that seen by a ground-based tracking radar (i.e., near- versus far-field radar cross sections).

Target size and shape are also important for determining whether a weapon projectile (bullet or warhead fragment) will impact the target. The probability of hit depends on the presented area of the target to the weapon projectile or fragmentation pattern. Example target classes of different size and shape, which should be separately examined for model validation include heavy bombers and cargo aircraft (e.g., B-52, B-1B, C-130), fighters (e.g., F-15, F-16, F-18), and drones or missiles (e.g., BQM-74, Tomahawk, ALCM, SCUD, JSOW).

Individual weapon intercept outcomes depend on a number of random variables and cannot be predicted deterministically. The validation of

issues in this category, therefore, requires the comparison of MOE distributions for model and test results. The four MOEs identified in Table 3.1 are miss distance, which is defined as the closest point of approach (CPA), the probability of fuzing that is appropriate for weapons with a fuze-activated warhead, the probability of hit, and the probability of kill (PK) given a hit.[2]

As mentioned previously, not all the validation issues are relevant for each susceptibility model. Those that are will depend on specific model capabilities and intended applications. Using Table 3.1 as a generic template, model-specific validation issues (the CAIs) can be straightforwardly developed. This process is illustrated for ESAMS and ALARM in the next section.

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[2]The scope of the SMART project is limited to susceptibility modeling; therefore, vulnerability, i.e., the conditional probability of kill given a hit will be considered a limitation to the scope of SMART validation (LIMSCOPE).

4. MODEL SPECIFIC PHASE II OBJECTIVES

Having briefly discussed the generic or model independent aspects of the Phase II model validation in Section 3, this section illustrates the development of model-specific CAIs for ESAMS and ALARM. Model-specific CAIs will depend on intended model uses that are limited by modeling resolution, available output quantities, and simplifying assumptions. After discussing the general model uses and limitations, we present a tentative list of CAIs and MOEs for both models. Some obvious subjectivity is involved when defining CAIs since two or more subobjectives may be combined into a single CAI to keep the overall number of CAIs manageable.

ESAMS

The ESAMS model was developed to predict the capabilities of radar and infrared guided SAM systems possessed by the former Soviet Union. The original model design and development date back to the late 1970s and are based on intelligence assessments and engineering estimates of Soviet SAM design and performance capabilities. BDM developed and currently maintains ESAMS under contract with the Air Force Studies and Analyses Agency (AFSAA). The model is written in FORTRAN, and the current version (2.6.2) consists of approximately 130,000 lines of code (50 percent of which are comments) in about 750 subroutines. ESAMS has been widely used in each of the services for aircraft survivability assessments, in numerous studies including cost and operational effectiveness analyses (COEAs), and in support of operational evaluations.

ESAMS contains a fairly detailed level of modeling and numerous user-selectable options. For example, the model can be run with a smooth, flat earth and a model-defined target flight path consisting of constant speed, heading, and altitude, or the user may model a specific geographical location and input Defense Mapping Agency (DMA) digital terrain elevation data and mission plan a more realistic flight path. The target signature may optionally include the effects of glint and

scintillation, terrain clutter is computed for any of a dozen different terrain types, and various options exist to model target endgame maneuvers, electronic countermeasures (ECM), and warhead fuzing.

Radar detection in ESAMS is basically modeled at the radar range equation level of detail with clutter and multipath optionally included. Target tracking is modeled via detailed range, angle, and Doppler tracking loops with system-specific filter and servo responses. The missile performance is modeled with equations of motion involving five degrees-of-freedom (roll stabilized) and uses thrust, mass, and drag data obtained from intelligence assessments or FME.

The user is responsible for defining most of the target-related characteristics in ESAMS. These include the target signature, vulnerability data, and ECM. Target signatures can be specified at arbitrary resolution in elevation and azimuth. Vulnerability data consist of blast kill radii and the location and size of aircraft vulnerable components. The types of ECM modeled include most types of deception generated by self-protection jammers (e.g., range and velocity gate pull-off techniques, swept square waves, etc.), in addition to chaff and towed decoys.

In spite of the numerous modeling options, several model assumptions and limitations also potentially preclude the model's use in certain applications. ESAMS is currently designed to model both the target acquisition and target tracking functions of the SAM fire control radar[1] and missile flyout at user-defined launch times. Other equipment normally deployed in a SAM fire unit may include additional target acquisition radars and command and control vehicles, which are not modeled. Typically, a target engagement sequence begins when the target acquisition radars first detect a target or targets. This information is then relayed to a command and control vehicle where the target tracks are fused and correlated with other target data possibly from remote sensors. Targets are prioritized and selected for engagement, and

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[1]Some of the SAM systems modeled have separate (but co-located) radars for acquisition and track while other systems use a single radar with separate acquisition and track modes.

target assignments are finally relayed to the fire control operators. The fire control radar must be slewed to the correct target azimuth and elevation angles; then the target is detected and locked-on.

An ESAMS simulation begins with the fire control radar already boresighted on the target; as soon as the SNR is sufficient to acquire and lock-on, a missile may be launched. This assumption, referred to as "perfect cueing," precludes the analysis of the various hand-off delays.

Another model limitation is related to the assumption of perfect cueing. ESAMS has only a limited capability to model target reacquisition following a break-lock in tracking. If sufficient angle or range errors are induced into the tracking loops (e.g., by clutter or deceptive electronic countermeasures [DECM]) to cause a loss of tracking, no capability exists to reacquire the target. If the break-lock occurs in the Doppler tracking loop of a missile seeker, however, reacquisition of the target Doppler frequency is modeled according to known or assessed capabilities of the specific seekers.

Other model limitations include the lack of standoff noise or deception jammers, e.g., the EF-111A or EA-6B, no man-in-the-loop (MITL) modeling, and the restriction to single target engagements.[2] Mission planning against SAM defenses normally includes standoff jammer support. Neglecting this support in the simulation restricts potential applications. The omission of MITL modeling precludes the analysis of important electronic counter-countermeasures (ECCM), such as manual tracking and mode switching, that further limits the model applicability. The restriction to single-target engagements, while adequate for many older Soviet SAM systems, does not accurately represent several of the more modern, phased-array systems with multi-target engagement capability. ESAMS does not provide an accurate representation of SAM effectiveness in any of these situations.

In applications for which the model limitations are acceptable, the single, most frequently used ESAMS output is the PK. For a given target signature, vulnerability, and flight path, the SAM engagement or PK envelope can be predicted. These engagement envelopes are frequently

[2]Many of the SAM systems modeled in ESAMS have multitarget engagement capabilities, but this capability is not modeled.

used as inputs to more highly aggregated models such as mission-level or campaign models or are used in relative comparisons for targets with different signature characteristics, electronic countermeasures, etc.

While the PK is probably the most frequently used model output, it is beyond the scope of the SMART validation effort. As described in Section 3, four phases are characteristic of a SAM engagement, and ESAMS outputs other useful information associated with each of these phases. For example, in the target detection phase, ESAMS can be used to predict target acquisition and lockon ranges as a function of target signature, profile, and environmental conditions. In the target tracking phase, mean track errors and cumulative distributions have been used to assess the effectiveness of different countermeasures. Missile fly-out modeling determines the kinematic engagement envelope (footprint) for a SAM system, and ESAMS-predicted missile trajectory or velocity profiles are frequent inputs to higher-level models such as mission-level or campaign-level models. Finally, in the weapon intercept phase, missile miss distances and probabilities of kill are frequently used to assess different target signatures, vulnerabilities, and endgame countermeasures. For a comprehensive model validation, all the available model outputs must be validated in each engagement phase.

Critical Analytical Issues

This subsection develops the CAIs for ESAMS validation based upon available model outputs and potentially stressing applications associated with each of the four weapon engagement phases described generically in Section 3.

Target Detection. Given that the ESAMS assumptions of perfect cueing and neglect of standoff ECM are acceptable for a particular analysis, target detection is the first phase in a SAM engagement. Most aircraft currently fielded have relatively large RF and IR cross sections ("conventional" signatures). For many ESAMS applications, the validation of detection ranges for aircraft with conventional signatures is sufficient. Other aircraft such as the F-117, B-2, and F-22 and some cruise missiles have LO signatures. LO signatures present a particularly stressing case for radar detection modeling since the

detection of LO aircraft (particularly at low altitude) requires that RF propagation and terrain clutter be accurately modeled. For this reason and the additional difficulty of gaining access to test data for validation involving LO aircraft, two separate target detection CAIs are proposed for each SAM sensor modeled:[3]

- How accurately does the ESAMS SA-X model predict target detection ranges for targets with conventional signatures in the absence of electronic countermeasures?
- How accurately does the ESAMS SA-X model predict target detection ranges for targets with LO signatures in the absence of electronic countermeasures?

Target Tracking. Once ESAMS has predicted that the target SNR is adequate for detection, the model transitions to the track mode and determines whether the SNR and SAM tracking response is adequate to lock on to and track the target. Target tracking is not only sensitive to the SNR but depends significantly on target maneuvers and DECM intended to induce range, angle, or Doppler errors into the tracking loops. Given the relatively large number of potential countermeasures that can be modeled in ESAMS, the best validation approach is to focus on the more benign conditions first, i.e., nonmaneuvering and maneuvering targets with no ECM first then subsequently extend the validation to include ECM focusing on a particular category of ECM separately (e.g., chaff, DECM. towed decoys, etc.).

Target tracking in some SAM systems is further complicated by the missile guidance mode. Many SAM systems employ command-guidance, which only requires target tracking by the fire control radar. Other SAM systems, however, employ a guidance mode referred to as semiactive homing in which the fire control radar tracks and illuminates the target with continuous wave (CW) RF energy; a seeker located on the missile also tracks the target via the reflected energy. For these semiactive

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[3]The most general case has three sensors: the acquisition radar (or acquisition mode of a multifunction radar), the track radar, and a missile seeker.

homing systems, both the ground-based radar and missile-seeker tracking must be validated.

Based on the preceding discussion, nine target tracking CAIs are proposed:

- How accurately does the ESAMS SA-X model predict target tracking errors for nonmaneuvering targets in the absence of electronic countermeasures?
- How accurately does the ESAMS SA-X model predict target tracking errors for maneuvering targets in the absence of electronic countermeasures?
- How accurately does the ESAMS SA-X model predict target tracking errors for nonmaneuvering and maneuvering targets in the presence of electronic countermeasures consisting of chaff?
- How accurately does the ESAMS SA-X model predict target tracking errors for nonmaneuvering and maneuvering targets in the presence of electronic countermeasures consisting of DECM?
- How accurately does the ESAMS SA-X model predict target tracking errors for nonmaneuvering and maneuvering targets in the presence of electronic countermeasures consisting of a towed decoy?
- How accurately does the ESAMS SA-X model predict target tracking errors for nonmaneuvering and maneuvering targets in the presence of electronic countermeasures consisting of terrain bounce jamming?
- How accurately does the ESAMS SA-X model predict missile-seeker tracking for semiactive homing missiles against nonmaneuvering targets in the absence of electronic countermeasures?
- How accurately does the ESAMS SA-X model predict missile-seeker tracking for semiactive homing missiles against maneuvering targets in the absence of electronic countermeasures?
- How accurately does the ESAMS SA-X model predict missile-seeker tracking for semiactive homing missiles against nonmaneuvering and maneuvering targets in the presence of electronic

countermeasures including chaff, DECM, towed decoys, and terrain bounce jamming?

Missile Flyout. Once a SAM system locks on to a target and launches a missile, tracking errors are computed and fed into a guidance computer (or auto-pilot in semiactive systems), and missile control surface corrections are computed to guide the missile to target intercept. Most of the engagement conditions that affect target tracking will also affect missile flyout (i.e., target maneuvers and countermeasures) but for simplicity are categorized into three CAIs for validation:

- How accurately does the ESAMS SA-X model predict missile fly-out trajectories and times of flight for nonmaneuvering targets in the absence of target countermeasures?
- How accurately does the ESAMS SA-X model predict missile fly-out trajectories and times of flight for maneuvering targets in the absence of target countermeasures?
- How accurately does the ESAMS SA-X model predict missile fly-out trajectories and times of flight for nonmaneuvering and maneuvering targets in the presence of target countermeasures including chaff, towed decoys, on-board self-protection jamming, or terrain bounce jamming?

Missile Intercept. The final phase of a SAM engagement is missile intercept or the endgame. The missile must be guided sufficiently close to the target so that the fuze will detect the target and detonate the warhead. The distance and target-missile orientation also determine warhead blast and fragment damage; therefore, accurate predictions of missile miss distance and the probability of fuzing are important model outputs.

At warhead detonation, ESAMS computes warhead blast and fragment damage based on user-defined blast radii and vulnerable components for the target of interest. As previously mentioned, the scope of the SMART validation precludes a vulnerability validation; therefore, the ESAMS

computed PK will not be validated. The PK, however, can be written as the product of a conditional probability of kill given a hit times the probability of hit. By definition, the probability of hit is part of the target susceptibility and technically within the scope of the SMART validation.

The validation of the ESAMS-predicted probability of hit requires destructive testing, which is usually a LIMSCOPE in OT. The expense of shooting down a tactical aircraft, particularly an LO aircraft, will preclude the complete validation of this model output. Some data may be obtainable for target drones or cruise missiles used in live-fire tests.

We propose three missile intercept CAIs for ESAMS validation:

- How accurately does the ESAMS SA-X model predict missile miss distance and endgame geometry distributions at the time of CPA?
- How accurately does the ESAMS SA-X model predict the probability of missile fuzing?
- How accurately does the ESAMS SA-X model predict the probability of hit given missile fuzing?

Measures of Effectiveness

Target detection and lock-on range are the appropriate MOEs for validating the ESAMS target acquisition CAIs. To adequately test the target acquisition CAIs, model predictions must be compared with test data for multiple nonmaneuvering profiles both radially toward the SAM radar and at fixed offsets from the radar, for several different aircraft types with conventional and LO signatures, and at several different altitudes.

Track error is the primary MOE for validating ESAMS target tracking predictions. This error occurs between the radar or missile seeker boresight and the actual target position. Modeled and actual track errors can be compared as either time series in azimuth, elevation, and range or as statistical distributions (for stationary time series). It is important not only that ESAMS accurately predicts track errors when the SAM radar is tracking but also that break-lock occurrences (caused by terrain masking, clutter, or ECM) are modeled accurately. As

mentioned previously, ESAMS does not model target reacquistion after a break-lock in tracking (except for Doppler reacquisition in missile seekers); therefore, some of the generic MOEs proposed in Section 3, such as the probability of track, mean track duration, and mean reacquisition time, are irrelevant except for missile-seeker modeling.

Modeled and measured missile fly-out trajectories are most easily contrasted by comparing times-of-flights and plots of x,y, and z position as a function of time or as a function of ground distance from the launch site. Often visual inspection is sufficient to estimate the accuracy; however, quantitative measures such as the root mean square (RMS) error or the correlation coefficient are also useful as single-valued quantitative measures.

Appropriate MOEs for missile intercept or endgame validation include missile miss distance, the probability of fuzing, the probability of hit given fuzing, and the probability of kill given a hit. Missile miss distance is defined as the point of closest approach to the target. The probability of fuzing is defined as the number of intercepts in which missile fuzing occurs divided by the total number of missile intercepts tested.

Undoubtedly, the PK is the single, most frequently used ESAMS output; however, as stated earlier, the PK includes a vulnerability component and is currently beyond the scope of the SMART validation. The probability of hit is a susceptibility measure, but its validation requires destructive testing, which generally is also a LIMSCOPE to operational testing.

Missile intercept MOEs are sensitive to random tracking and guidance errors, endgame target maneuvers, and ECM; therefore, single intercept comparisons are not sufficient. It is necessary to characterize the distribution of missile intercept MOEs such as missile miss distance and to compare the distribution means and standard deviations from testing and model prediction. The expense of testing a statistically significant number of telemetered threat missiles against target drones will generally preclude complete resolution of the endgame CAIs.

Notional test plans developed from the ESAMS CAIs and MOEs listed in this section are described in Appendix A. Each test consists of three sections: (1) the statement of objective that is based on a specific CAI, (2) the test procedure that identifies important test conditions, target profiles, and test data, and (3) the data analysis.

ALARM

ALARM is a generic radar detection model that can be used to compute the probability of target detection for potentially all types of land- or sea-based radars. Like ESAMS, ALARM is a government-owned model and is widely used in aircraft survivability assessments. ALARM was developed and is currently maintained by Science Applications International Corporation (SAIC) under contract with the Air Force Wright Laboratories (AF/WL). The model is written in FORTRAN, and the current version (ALARM 91) consists of approximately 23,000 lines of code (40 percent comments) in about 100 subroutines.

Radar detection in ALARM is basically modeled at the radar range equation level of detail with separate algorithms for low or medium pulse repetition frequency (PRF) radars with moving target indication (MTI) and pulsed Doppler or CW radars. Like ESAMS, several user-selectable options are available to enhance the modeling realism. For example, ALARM can be executed in either a featureless terrain mode (round, smooth earth) or in a site-specific mode that uses DMA digital terrain elevation data to compute terrain masking, multipath, and diffraction. Other options include the capability to model one or more standoff noise jammers (e.g., EF-111A or EA-6B) and the radar cross section (RCS) enhancement from rotor blades on rotary-wing aircraft.

Also like ESAMS, ALARM incorporates certain modeling assumptions and limitations that potentially preclude its use in certain applications. For example, ALARM is not a time-based simulation and does not model antenna scan. The antenna is always pointed in azimuth toward the true target location, and no scan-to-scan correlation information is used to compute the probability of detection. In reality, the assertion is that an experienced radar operator can use scan-to-scan signal correlation (i.e., M hits out of N scans) to improve

the probability of detection. The neglect of antenna scan also introduces errors in predicted detection ranges for "pop-up" targets, i.e., targets that become unmasked during a scan period when the antenna beam is at a different azimuth angle.

Another ALARM limitation is the antenna pattern representation. The model user defines antenna patterns by entering the gain at a fixed angular resolution along one cut in azimuth (elevation angle constant) and one cut in elevation (constant azimuth). The full three-dimensional pattern is then constructed by means of linear interpolation in azimuth and elevation. This assumption introduces errors for multi-beam radars and for antenna sidelobe characterization that could invalidate model use in applications involving sidelobe jamming or in applications requiring accurate clutter prediction (i.e., for LO targets).

For user-specified radar and antenna characterization data and aircraft signature and location data, ALARM computes basically three output quantities: the detected target power, clutter power, and the signal-to-interference ratio. The model will also indicate whether the target is masked or unmasked by terrain, and if unmasked whether it is detected or not based on the user-specified target fluctuation statistics and desired probabilities of detection and false alarm. ALARM validation, therefore, requires a comparison of model-predicted probabilities of detection to actual flight test data.

One complication that arises for ALARM validation is the lack of standard radar and antenna input data. The developers of ALARM assumed each model user would provide the radar and antenna data necessary to characterize the system they wished to model. Analysts typically consult available intelligence sources for data; however, the available multiple sources are not always consistent, which can lead to different performance predictions. This problem will be avoided within the SMART project by using data sets developed from measured hardware data. The ALARM radar and antenna data extracted from S&TI data and used for the functional element validation will be considered part of the "model" and used in the Phase II validation.

Critical Analytical Issues

Since ALARM is only a sensor model and not a weapon system model like ESAMS, only the first category of validation issues in Table 3.1 is relevant. Similar to ESAMS applications, the majority of ALARM applications will involve aircraft with conventional signatures. For this reason and the fact that LO signatures will critically stress the accuracy of signal propagation and clutter modeling, separate CAIs are proposed for targets with conventional and LO signatures. Also since different algorithms are used to model low and medium PRF radars versus pulsed Doppler or CW radars, these two radar classes must be validated separately by representative systems.[4]

The ALARM option of predicting target probabilities of detection in the presence of standoff noise jamming is a sufficiently critical application to require separate validation; therefore, a separate CAI is proposed. In addition, the extensive spherical earth knife-edge (SEKE) diffraction code integrated into ALARM 91 requires separate validation.[5]

Based on these model considerations, we propose the following six CAIs:

- How accurately does the ALARM model predict the probability of target detection for pulsed radars against targets with conventional radar cross sections in the absence of standoff noise jamming?
- How accurately does the ALARM model predict the probability of target detection for pulsed radars against targets with LO radar cross sections in the absence of standoff noise jamming?
- How accurately does the ALARM model predict the probability of target detection for pulse Doppler or CW radars against targets

[4]While the ALARM "code" can be validated generically by validating the model outputs for several representative systems, the ALARM "model" must encompass the threat-specific input data and requires validation on a system-by-system basis using comparisons to actual test data.

[5]Purportedly this code has been validated by MIT Lincoln Laboratories; however, its integration into ALARM requires separate validation. Knife-edge diffraction is particulary important for low-frequency RF propagation, e.g., associated with very high frequency (VHF) radars.

with conventional RCSs in the absence of standoff noise jamming?

- How accurately does the ALARM model predict the probability of target detection for pulse Doppler or CW radars against targets with LO radar cross sections in the absence of standoff noise jamming?
- How accurately does the ALARM model predict the probability of target detection for pulsed and pulse Doppler radars in the presence of standoff noise jamming?
- How accurately does the ALARM model predict terrain masking and diffraction?

Measures of Effectiveness

As previously mentioned in Section 2, operational MOEs are appropriate for the Phase II validation. ALARM computes and outputs target signal powers, clutter powers, and signal-to-interference ratios as a function of input target cross section and profile and indicates whether the target is masked, unmasked *(but not detected), or* detected. Only this last output (i.e., the specification of target detection as a function of range) is operationally measurable without special instrumentation and is the primary MOE for the ALARM Phase II validation.

Initial detection range is an important analytical MOE but not the only one. The accurate prediction of terrain masking, clutter or ECM masking, and antenna nulls must also be validated. This can be done using the probability of correct correlation, which is simply defined as the ratio of correctly predicted detection opportunities or detection intervals divided by the total number of detection opportunities or detection interval.

Notional test plans for Phase II ALARM validation based on the CAIs and MOEs in this section are described in Appendix B.

5. VALIDATION PRIORITIES

One objective of this report is to identify a reasonably comprehensive set of validation requirements for Phase II or integrated model validation for the set of models being considered in the SMART project. As described generically in Section 3, these requirements can be categorized by the different engagement phases modeled with different requirements characteristic to each phase. Specific requirements are developed for ESAMS and ALARM based on model uses in Section 4 and are referred to as CAIs. These CAIs are stated as questions of the form: "How accurately does the model predict. . . ." The validation approach advocated by the SMART project consists of resolving these CAIs by comparing the model outputs to laboratory and field test data from the actual hardware being modeled.

In general, extensive field testing probably will not be conducted exclusively to support model validation. Field testing is expensive but essential for other purposes such as training, test, and evaluation of weapon systems. S&TI centers also field test exploited threat systems to characterize performance capabilities. Data collection is typically not a high priority during training exercises; however, operational test and evaluation and S&TI tests are both potentially useful sources of data for model validation and may be leveraged by additional resources when necessary.

Typically, the lack of available field test data for certain CAIs or small sample sizes for others will preclude a comprehensive model validation. Simply too many combinations of threat types, target types, flight profiles, environmental conditions, and countermeasures exist to test them all with statistical confidence. On the other hand, a comprehensive model validation does not have to be completed before a model can be validly used for specific applications. One benefit of the CAI approach is that by decomposing the overall model validation into multiple, independent objectives, these individual objectives (i.e., CAIs) may be validated sequentially on a priority basis. Once a

particular CAI has been validated, the model can be accredited for that specific application.

How should the CAIs be prioritized for validation? This consideration is important since once a prioritization has been established, it determines how to allocate available resources. Initial model validation should prioritize the CAIs based on the most common model applications, but subsequent prioritization may be driven by specific model applications. For example, an F-22 study might require the validation of LO detection modeling, whereas a study involving the F-15E TEWS might require electronic countermeasure validation. As a general rule, the more benign or less stressing CAIs should be validated before more stressing CAIs. It does not make sense to validate target tracking in the presence of countermeasures before validating target tracking without countermeasures because if the latter is invalid, the former is probably invalid also.

Based on the common uses of ESAMS and ALARM, what validation priorities can be recommended?

ESAMS

The most basic use of ESAMS is the computation of PK envelopes for RF SAMs. For aircraft with conventional RCS (5 to 10 dB or greater) in the absence of countermeasures, the PK envelope will be determined either by the kinematic range of the missile for targets at medium to high altitude or by the radar horizon for targets at low altitude and by the vulnerability of the target aircraft. The validity of the missile flyout and endgame modeling are most important for these applications. Moreover, for applications that require only the PK envelope, the specific missile trajectory is not critical—only the maximum range, altitude, and, to a lesser extent, the weapon speed (that determines the intercept point) are the only missile fly-out quantities that need to be validated. These quantities are largely determined by the propulsion and aerodynamic characteristics of the missile and are insensitive to target type.

The primary weapon intercept or endgame CAIs that are important for aircraft with conventional RCS are the probability of fuzing and the PK

given fuzing. Both the probability of fuzing and the PK given fuzing are aircraft-specific and depend on the missile-aircraft endgame geometry. The validation of the probability of fuzing requires the comparison of model results to a relatively large number of missile encounters at various miss distances and endgame geometries. This amount of data will not be available from telemetered live firings and will require laboratory testing. The PK given fuzing depends on the vulnerability to blast and warhead fragments, the endgame encounter geometry, and the kill category required ("KK", "K", "A", etc.). In ESAMS, aircraft vulnerability is defined by input data that have to be separately validated.

For aircraft with reduced or LO RCS, target detection and tracking CAIs have a greater impact on the size and shape of the PK envelope. Radar detection in ESAMS is based on the radar range equation. This equation has been independently validated by extensive empirical data and does not require revalidation in ESAMS for free-space detection (i.e., detection at medium to high altitude where terrain clutter is not significant). The resolution of free-space target detection CAIs then only requires that the variables in the radar range equation such as power, wavelength, antenna gain, target cross section, etc., be validated. For low-altitude targets, terrain clutter and multipath propagation are important. Computational methodologies for predicting clutter and multipath and clutter rejection in the radar receiver have not been independently validated to the extent of the radar range equation and, therefore, require explicit validation in ESAMS.

Another set of important ESAMS applications is the prediction of electronic countermeasures on SAM effectiveness, and the largest class of countermeasures is probably DECM. DECM techniques are generally designed to disrupt the target tracking radar or missile seeker; therefore, the validation of ESAMS for these applications requires the validation of target tracking CAIs both without (dry) and with DECM (wet). Both the track error dispersion and error response to changes in range and angle rates (dry and wet) are critical for modeling DECM effectiveness and should be validated after missile flyout, endgame, and detection CAIs.

The set of CAIs just discussed is summarized in priority order below:

1. Missile Flyout—nonmaneuvering; no ECM
2. Missile Intercept—probability of hit
3. Target Detection—conventional signatures
4. Target Detection—LO signatures
5. Target Tracking—nonmaneuvering targets; no ECM
6. Target Tracking—nonmaneuvering targets; DECM.

This initial list covers a majority of ESAMS applications. The other CAIs defined in Section 4 can be addressed as needed to support specific model applications.

ALARM

The scope of validation for ALARM is much narrower than ESAMS and focuses only on radar detection. The majority of ALARM applications deal with detection of both conventional and LO target signatures in the absence of countermeasures. For this reason, the CAIs for pulsed and pulse Doppler detection of conventional targets with no countermeasures are recommended with the highest priority, followed by the CAIs for pulsed and pulse Doppler detection of LO targets with no countermeasures. These CAIs are followed with lower priority by detection in the presence of standoff noise jamming and by the CAI for terrain masking and diffraction. This order is summarized below:

1. Target Detection—pulsed radars; conventional signatures
2. Target Detection—pulse-Doppler radars; conventional signatures
3. Target Detection—pulsed radars; LO signatures
4. Target Detection—pulse-Doppler radars; LO signatures
5. Target Detection—standoff jamming
6. Target Detection—terrain masking and diffraction.

Similar to ESAMS, the probability of detection for free-space detection in ALARM is based on the radar range equation. Aircraft with

conventional signatures require primarily the validation of input data. For low-altitude aircraft, particularly aircraft with LO signatures, terrain clutter and multipath require explicit validation. The prediction of detection ranges in the presence of standoff jamming and the prediction of terrain masking or knife-edge diffraction are less common ALARM applications and are consequently prioritized below the other CAIs.

A. ESAMS TEST DESCRIPTIONS

TEST ESAMS-1: TARGET DETECTION—CONVENTIONAL SIGNATURES

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target detection ranges for targets with conventional signatures in the absence of electronic countermeasures.

Procedure

Flight testing will be conducted with both fixed and rotary wing aircraft having conventional signatures. The target aircraft will fly straight and level profiles starting beyond the maximum detection range of the test system and will ingress at a constant heading. The target will maintain this nonmaneuvering profile flying past the test system and egressing until beyond maximum detection range. Multiple runs will be flown with each of several different target types at several different altitudes (e.g., 200, 1500, and 20,000 feet) and with initial points and headings chosen to examine several different cross-range offsets. Low altitude profiles will be flown at a constant above ground-level (AGL) altitude and will be chosen to provide intervals of terrain masking. The high altitude profiles will be flown at a constant mean sea-level (MSL) altitude.

Test data required include time-space-position information (TSPI) for all target profiles, blip-to-scan time histories for the acquisition radar from which the initial detection range, mask ranges or lose detect ranges, MTI blind speeds, Doppler notches, etc., will be extracted. Additional data items required include the effective radiated power of the radar, a clutter map of the site, dynamic target RCS measurements or target RCS estimation using calibration spheres, and latitude, longitude, and altitude of the test system to reference terrain features of the test facility to DMA digital terrain elevation data.

Data Analysis

The target RCS, TSPI data, and terrain elevation and clutter data will be used as inputs to the ESAMS model. Target detection as a

function of range will be computed with the model for the acquisition radar and compared with the flight test results. Statistical analyses (e.g., t-test, Wilcoxon, Kolmogorov-Smirnov, etc.) will determine the accuracy of mean detection ranges by target type averaged over all profiles.

Target detections computed with the model will also be compared to test data to correlate segments of flight profiles in which detection was lost because of clutter, terrain masking, MTI blind speeds, Doppler notches, etc. These comparisons will be presented graphically as a function of mission time or range from the radar and will be summarized by the probability of correct correlation defined as the ratio of correctly predicted scans (or scan intervals) divided by the total number of scans (or profile time).

TEST ESAMS-2: TARGET DETECTION—LO SIGNATURES

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target detection ranges for targets with LO signatures in the absence of ECMs.

Procedure

This test will be conducted with the same procedure used in Test ESAMS-1 with available LO targets.

Data Analysis

Data analysis will be identical to Test ESAMS-1.

TEST ESAMS-3: TARGET TRACKING—NONMANEUVERING TARGETS

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target tracking errors for nonmaneuvering targets in the absence of ECMs.

Procedure

This test will be conducted in conjunction with Test ESAMS-1. After initial target detection, the target will be handed off to the track radar and tracked throughout the remainder of the profile. If a

break-lock occurs after the initial lockon, range reference radars may be used to reposition the radar boresight and facilitate reacquisition. In addition to the data items specified in Test ESAMS-1—namely dynamic target RCS or calibration spheres, TSPI, and a site clutter map—Test ESAMS-2 requires target azimuth, elevation, and range measured by the test radar and the computed track errors in azimuth, elevation, and range measured with respect to the reference radar as a function of mission time.

Data Analysis

Target RCS, TSPI data, and terrain elevation and clutter will be used as inputs to the ESAMS model. Predicted track errors in azimuth, elevation, and range will be computed and compared with the flight test data. Graphical plots and time series analyses will be used to analyze the accuracy and dispersion of the predicted ESAMS tracking errors.

TEST ESAMS-4: TARGET TRACKING—MANEUVERING TARGETS

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target tracking errors for maneuvering targets in the absence of electronic countermeasures.

Procedure

The procedure for this test is similar to that for Test ESAMS-3, except that target profiles will involve a two-dimensional, 3g weave.

Data Analysis

The data analysis for this test is identical to Test ESAMS-3.

TEST ESAMS-5: TARGET TRACKING—ECM (CHAFF)

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target tracking errors for nonmaneuvering and maneuvering targets in the presence of electronic countermeasures consisting of chaff.

Procedure

This test requires target tracking data similar to that identified in Tests ESAMS-3 and ESAMS-4 and may be conducted in conjunction with those tests by including the manual deployment of chaff on some target passes. In addition to the data specified in Tests ESAMS-3 and ESAMS-4, this test requires the ejection time of each chaff bundle.

Data Analysis

Target RCS, TSPI data, terrain elevation and clutter, and chaff deployment times will be used as inputs to the ESAMS model. Predicted track errors in azimuth, elevation, and range will be computed and compared with the flight test data. Graphical plots and time series analyses will be used to analyze the accuracy and dispersion of the predicted ESAMS tracking errors. The number of target break-locks and reacquisition times will also be compared.

TEST ESAMS-6: TARGET TRACKING—ECM (DECM)

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target tracking errors for nonmaneuvering and maneuvering targets in the presence of ECMs consisting of DECM.

Procedure

This test will require target tracking data similar to that identified in Tests ESAMS-3 and ESAMS-4 and may be conducted in conjunction with those tests by including DECM on some of the target passes. In addition to the data specified in Tests ESAMS-3 and ESAMS-4, this test requires jammer characterization data including power and antenna gain, jammer on/off times, and the transmitted waveform description.

Data Analysis

Target RCS, TSPI data, terrain elevation and clutter, and jammer characterization and waveform data will be used as inputs to the ESAMS model. Predicted track errors in azimuth, elevation, and range will be computed and compared with the flight test data. Graphical plots and

time series analyses will be used to analyze the accuracy and dispersion of the predicted ESAMS tracking errors. The number of target breaklocks and reacquisition times will also be compared.

TEST ESAMS-7: TARGET TRACKING—ECM (TOWED DECOY)

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target tracking errors for nonmaneuvering and maneuvering targets in the presence of ECMs consisting of a towed decoy.

Procedure

This test will require target tracking data similar to that identified in Tests ESAMS-3 and ESAMS-4 and may be conducted in conjunction with those tests by deploying a towed decoy on some target passes. In addition to the data specified in Tests ESAMS-3 and ESAMS-4, this test requires the towed decoy deployment time, deployment rate, decoy orientation (distance and angle) with respect to the aircraft, decoy characterization data including power and antenna gain pattern, jammer on/off times, and the decoy waveform description.

Data Analysis

Target RCS, TSPI data, terrain elevation and clutter, and decoy deployment time, characterization, and waveform data will be used as inputs to the ESAMS model. Predicted track errors in azimuth, elevation, and range will be computed and compared with the flight test data. Graphical plots and time series analyses will be used to analyze the accuracy and dispersion of the predicted ESAMS tracking errors.

TEST ESAMS-8: TARGET TRACKING—ECM (TBJ)

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts target tracking errors for nonmaneuvering and maneuvering targets in the presence of ECMs consisting of terrain bounce jamming (TBJ).

Procedure

This test will require target tracking data similar to that identified in Tests ESAMS-3 and ESAMS-4 and may be conducted in conjunction with those tests by deploying TBJ on some of the low-altitude target passes. In addition to the data specified in Tests ESAMS-3 and ESAMS-4, this test requires jammer characterization data including power and antenna gain pattern, jammer on/off times, and the waveform description.

Data Analysis

Target RCS, TSPI data, terrain elevation and clutter, and terrain bounce jammer characterization and waveform data will be used as inputs to the ESAMS model. Predicted track errors in azimuth, elevation, and range will be computed and compared with the flight test data. Graphical plots and time series analyses will be used to analyze the accuracy and dispersion of the predicted ESAMS tracking errors. The number of target break-locks and reacquisition times will also be compared.

TEST ESAMS-9: MISSILE SEEKER TRACKING—NONMANEUVERING TARGETS

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile seeker tracking for semiactive homing missiles against nonmaneuvering targets in the absence of electronic countermeasures.

Procedure

The primary source of data for this test will be captive-carried missile seekers. A second source of data will be telemetered live missile firings when available. The target aircraft will fly straight and level profiles radially toward the ground-based target tracking radar and at various offsets. Target passes will consist of multiple low-, medium-, and high-altitude profiles at several different airspeeds. The airborne seeker testbed will fly simulated missile profiles against the target at several different ranges. The ground-based, target-tracking and target-illumination radars must be

transmitting and tracking the target. Test data required include target and airborne testbed TSPI, target signature, effective radiated power of the target illuminator at the missile seeker, missile seeker tracking errors, and seeker clutter.

Data Analysis

The target and airborne seeker testbed TSPI, target RCS, and terrain elevation and clutter will be used as inputs to the ESAMS model. The model will be run with the user-defined missile flight path option using the airborne seeker testbed TSPI. Predicted seeker track errors in azimuth and elevation will be computed and compared with the flight test data. Graphical plots and time series analyses will be used to analyze the accuracy and dispersion of the predicted ESAMS seeker tracking errors.

TEST ESAMS-10: MISSILE SEEKER TRACKING—MANEUVERING TARGETS

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile seeker tracking for semiactive homing missiles against maneuvering targets in the absence of ECMs.

Procedure

The procedure for this test is similar to that for Test ESAMS-9, except that target profiles will involve a two-dimensional, 3g weave.

Data Analysis

The data analysis for this test is identical to Test ESAMS-9.

TEST ESAMS-11: MISSILE SEEKER TRACKING—ECM

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile seeker tracking for semiactive homing missiles against nonmaneuvering and maneuvering targets in the presence of electronic countermeasures including chaff, DECM, towed decoys, and terrain bounce jamming.

Procedure

This test requires seeker tracking data similar to that identified for Tests ESAMS-9 and -10. This test may be conducted in conjunction with those tests by including ECM on some target passes. ECM characterization data similar to those identified in Tests ESAMS-5-8 are required.

Data Analysis

The data analysis for this test is similar to Test ESAMS-9. In addition to seeker tracking errors, the number of target break-locks caused by ECM and seeker reacquisition times will also be computed.

TEST ESAMS-12: MISSILE FLYOUT—NONMANEUVERING TARGETS

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile flyout trajectories and times-of-flight for nonmaneuvering targets in the absence of electronic countermeasures.

Procedure

The procedure for this test requires telemetered live missile firings of the SA-X system against target drones. Target profiles will be straight and level flybys with altitudes and airspeeds chosen to exercise all guidance modes of the system, except those guidance modes used exclusively in the presence of ECM.

The data required for this test include target signature and TSPI, atmospheric data (winds, air density, and temperature as a function of altitude), system latitude and longitude, site clutter map, time of missile launch, time of flight to missile intercept or CPA, and missile position, velocity vectors (Cartesian coordinates), and orientation (roll, yaw, pitch) as a function of fly-out time.

Data Analysis

The target TSPI, terrain elevation and clutter, and wind data will be used as inputs to the ESAMS model. If the atmospheric density profile is significantly different from the standard atmosphere used in the simulation, these data will also be used via a lookup table. The

model will be executed with missile launch times and guidance modes corresponding to those in the tests and the resulting missile trajectories computed. The observed and computed trajectories will be compared graphically by plotting down-range, cross-range, and altitude components of missile position and speed profiles as a function of mission time. Errors between measured and computed missile position components and speed will also be quantified by computing and tabulating the RMS errors. Measured and computed times-of-flight and the relative error will also be reported.

TEST ESAMS-13: MISSILE FLYOUT—MANEUVERING TARGETS

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile flyout trajectories and times-of-flight for maneuvering targets in the absence of electronic countermeasures.

Procedure

The procedure for this test is similar to that of Test ESAMS-12 except that target profiles will involve a two-dimensional 3g weave.

Data Analysis

The data analysis for this test is identical to Test ESAMS-12.

TEST ESAMS-14: MISSILE FLYOUT—ECM

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile flyout trajectories and times-of-flight for nonmaneuvering and maneuvering targets in the presence of ECMs including chaff, DECM, towed decoys, and terrain bounce jamming.

Procedure

The procedure for this test is similar to those of Tests ESAMS-12 and -13. The presence of ECMs may induce alternative guidance modes or ECCM features of the hardware.

DATA ANALYSIS

The data analysis for this test is identical to Tests ESAMS-12 and -13.

TEST ESAMS-15: MISSILE INTERCEPT—MISS DISTANCE

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts missile miss distance and endgame geometry distributions at the time of CPA.

Procedure

The validation of model predicted miss distances requires the measurement of miss distance from live missile firings to a precision of 1 meter or less. The miss distance will be defined as the missile distance from the target centroid at the time of CPA. Missile miss distance and missile-target body orientations are critical inputs to the subsequent determination of the probabilities of hit and kill.

Missile intercept MOEs are sensitive to random tracking and guidance errors, endgame maneuvers, and ECM; therefore, the comparison of MOE distributions rather than single flyout results are necessary. These data can be obtained from the live-fire testing described in Tests ESAMS-12-14.

Data Analysis

Target RCS, TSPI, terrain elevation, clutter, ECM characterization and missile time-of-launch data will be used as inputs to the ESAMS model. Multiple Monte Carlo replications of the model will be run for each test condition, and the proportion of model runs as a function of miss distance will be plotted. The test results will be plotted as an overlay to the model results, and an accuracy assessment will be made based on a comparison of mean miss distances and the relative dispersions of the model and test distributions. This comparison will be made separately for nonmaneuvering targets, maneuvering targets, and targets in the presence of ECM.

TEST ESAMS-16: MISSILE INTERCEPT—MISSILE FUZING

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts the probability of missile fuzing.

Procedure

This test may be conducted in conjunction with the live-fire tests described in ESAMS-12-14. The time of missile fuzing is one desired data item from the telemetry unit. In addition to the live-fire data, a supplemental source of data for the resolution of this CAI may be available from Phase I or functional element validation testing. Fuzing data can also be obtained from laboratory testing in which a missile fuze is mounted on a track and run by an actual aircraft target or scale model suspended in various orientations. This type of testing is done at several laboratories such as the Encounter Simulation Laboratory (ESL) in Corona, Calif. This type of test data is particularly useful to assess the probability of fuzing for LO targets.

Data Analysis

For the live fire test data, target RCS, TSPI, terrain elevation, clutter, ECM characterization, and time-of-launch data will be used as inputs to the ESAMS model. Multiple Monte Carlo replications of the model using both the glitter-point endgame model (the default) and the advanced fuze model will be run for each test condition, and the probability of fuzing as a function of miss distance will be computed for both the test data and model runs.

For the laboratory data (if available), ESAMS will be run with the missile flight path simulated in testing specified as input. Similar to the procedure for the live-fire data, the probability of fuzing will be computed for both the glitter point and advanced fuze models and compared to test results.

TEST ESAMS-17: MISSILE INTERCEPT—PROBABILITY OF HIT

Objective

The objective of this test is to determine how accurately the ESAMS SA-X model predicts the probability of hit given missile fuzing.

Procedure

The resolution of this CAI will be based on static warhead detonation data used for Phase I or functional element validation. Blast and fragmentation data consisting of fragment mass and velocity distributions as a function of distance and aspect angle from the warhead are required.

Data Analysis

The probability of hit is defined as the probability that warhead detonation will result in physical damage to the target.[1] For modeling purposes, target damage is defined as any intercept that results in a PK that is greater than zero. The validation of the probability of hit, therefore, requires an assessment of both the warhead blast and fragmentation modeling and target vulnerability data.

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[1]The probability that this damage will impair the target from accomplishing its intended mission is the conditional probability of kill given a hit and is a function of the target vulnerability.

B. ALARM TEST DESCRIPTIONS

TEST ALARM-1: PULSED RADARS VERSUS CONVENTIONAL SIGNATURES

Objective

The objective of this test is to determine how accurately the ALARM model predicts target detection ranges for pulsed radars against targets with conventional signatures in the absence of electronic countermeasures.

Procedure

This test will require target detection data from a representative sample of pulsed radars against both fixed and rotary wing aircraft having conventional signatures. The target aircraft will fly straight and level profiles starting beyond the maximum detection range of the test system and will ingress at a constant heading until detected. After initial detection, the target aircraft will turn and egress in the opposite direction until the track is lost. Multiple runs will be flown with each of several different target types at several different altitudes (e.g., 200, 1500, and 20,000 feet) and with initial points and headings chosen to examine several different cross-range offsets. Low altitude profiles will be flown at a constant AGL altitude and will be chosen to provide intervals of terrain masking. The high-altitude profiles will be flown at a constant MSL altitude.

Test data required include TSPI for all target profiles, blip-to-scan time histories for the test radars from which the initial detection range, mask ranges or lose detect ranges, MTI blind speeds, etc., will be extracted. Additional data items required include a clutter map of the site, dynamic target RCS measurements or target RCS estimation using calibration spheres, and latitude, longitude, and altitude of the test system to reference terrain features of the test facility to DMA digital terrain elevation data.

Data Analysis

The target RCS, TSPI data, and terrain elevation and clutter data will be used as inputs to the ALARM model. Target detection as a

function of range will be computed with the model for the test radars and compared with the flight test results. Statistical analyses will determine the accuracy of mean detection ranges by target type averaged over all profiles.

Target detections computed with the model will also be compared to test data to correlate segments of flight profiles in which detection was lost because of clutter, terrain masking, MTI blind speeds, etc. These comparisons will be presented graphically as a function of mission time or range from the radar and will be summarized by the probability of correct correlation defined as the ratio of correctly predicted scans (or scan intervals) divided by the total number of scans (or profile time).

TEST ALARM-2: PULSED RADARS VERSUS LO SIGNATURES

Objective

The objective of this test is to determine how accurately the ALARM model predicts target detection ranges for pulsed radars against targets with LO signatures in the absence of electronic countermeasures.

Procedure

This test will be conducted with the same procedure used in Test ALARM-1 using available LO targets.

Data Analysis

Data analysis will be identical to Test ALARM-1.

TEST ALARM-3: PULSED DOPPLER RADARS VERSUS CONVENTIONAL SIGNATURES

Objective

The objective of this test is to determine how accurately the ALARM model predicts target detection ranges for pulsed Doppler radars against targets with conventional signatures in the absence of ECMs.

Procedure

This test will be conducted with the same procedure used in Test ALARM-1 using pulsed Doppler radars.

Data Analysis

Data analysis will be identical to Test ALARM-1.

TEST ALARM-4: PULSED DOPPLER RADARS VERSUS LOW OBSERVABLE (LO) SIGNATURES

Objective

The objective of this test is to determine how accurately the ALARM model predicts target detection ranges for pulsed Doppler radars against targets with LO signatures in the absence of ECMs.

Procedure

This test will be conducted with the same procedure used in Test ALARM-3 using available LO targets.

Data Analysis

Data analysis will be identical to Test ALARM-1.

TEST ALARM-5: ELECTRONIC COUNTERMEASURES (ECM)

Objective

The objective of this test is to determine how accurately the ALARM model predicts target detection ranges for both pulsed and pulsed Doppler radars against targets in the presence of standoff noise jamming.

Procedure

In addition to the target aircraft, this test will require the presence of a standoff jamming aircraft. As in the other tests, the target aircraft will fly straight and level profiles at a constant MSL altitude starting beyond the maximum detection (burn-though) range and will ingress at a constant heading until detected. After initial detection, the target aircraft will turn and egress in the opposite direction until the track is lost. Multiple runs will be flown with each of several different target types at several different altitudes, and the standoff jammer will be stationed at several different ranges and altitudes with variable angular separation with respect to the target aircraft.

Test data required include target and jammer TSPI, blip-to-scan time histories for the test radars from which the initial detection range, mask ranges or lose detect ranges, MTI blind speeds, etc., will be extracted. Jammer characterization data required include jammer power, antenna gain, on/off times, center frequency, and bandwidth. Additional data items required include a clutter map of the site, dynamic target RCS measurements or target RCS estimation using calibration spheres, and latitude, longitude, and altitude of the test system to reference terrain features of the test facility to DMA digital terrain elevation data.

Data Analysis

The target RCS and TSPI, jammer position and power, and terrain elevation and clutter will be used as inputs to the ALARM model. Target detection as a function of range will be computed with the model for the test radars and compared with the flight test results. Statistical analyses will determine the accuracy of mean detection ranges by target type averaged over target profiles and jammer power and geometries.

Target detections computed with the model will also be compared to test data to correlate segments of flight profiles in which detection was lost because of jamming, clutter, terrain masking, MTI blind speeds, etc. These comparisons will be presented graphically as a function of mission time or range from the radar and will be summarized by the probability of correct correlation defined as the ratio of correctly predicted scans (or scan intervals) divided by the total number of scans (or profile time).

TEST ALARM-6: RF PROPAGATION

Objective

The objective of this test is to determine how accurately the ALARM model predicts terrain masking and diffraction.

Procedure

Since RF diffraction and multipath are most pronounced at very high frequencies (VHF), frequencies, this test will compare measured and predicted detection ranges from one or more VHF radars against low-

altitude targets. For this test, target aircraft will fly terrain following (constant AGL) profiles at constant headings starting beyond the radar horizon and ingressing past the test system. Targets may egress along the same or a different heading until past the radar horizon. Some of the profiles should contain terrain masked intervals to examine knife-edge diffraction of the RF signal.

Test data required include TSPI for all target profiles, blip-to-scan time histories for the test radars from which the initial detection range, mask ranges or lose detect ranges, MTI blind speeds, Doppler notches, etc., will be extracted. Additional data items required include a clutter map of the site, dynamic target RCS measurements or target RCS estimation using calibration spheres, and latitude, longitude, and altitude of the test system to reference terrain features of the test facility to DMA digital terrain elevation data.

Data Analysis

Data analysis will be identical to Test ALARM-1.

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